23F

March 2001 WGM

file name: ucrl143848.pdf

Summary pages 1 to 10

NASA Ames pp 84 to 92

UCRL-ID-143848

Working Group Meeting on
cle Aerodynamic Drag:
ns and Summary of Comments
sions

. Greenman, D. Flowers, T. Dunn, J. skowski , LLNL; F. Browand A. Knight, and , University of Southern California; A. Leoard and M. Rubel, California Institute of Technology; K. Salari and W. Rutledge, Sandia National Laboratories; J. Ross, D. Satran, J.T. Heineck, S. Walker, D. Driver, B. Storms, NASA Ames Research Center

U.S. Department of Energy
Lawrence Livermore National Laboratory

May 14, 2001

UCRL-ID-143848

March 2001 Working Group Meeting on Heavy Vehicle Aerodynamic Drag: Presentations and Summary of Comments and Conclusions

R. McCallen, R. Greenman, D. Flowers, T. Dunn, J. Owens, G. Laskowski , LLNL; F. Browand A. Knight, and M. Hammache, University of Southern California; A. Leoard and M. Rubel, California Institute of Technology; K. Salari and W. Rutledge, Sandia National Laboratories; J. Ross, D. Satran, J.T. Heineck, S. Walker, D. Driver, B. Storms, NASA Ames Research Center

U.S. Department of Energy

Lawrence Livermore National Laboratory

May 14, 2001

DISCLAIMER

This work was performed under the auspices of the U. S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

March 2001
Working Group Meeting on
Heavy Vehicle Aerodynamic Drag:
Presentations and Summary of Comments and Conclusions

Jointly written by
Lawrence Livermore National Laboratory
Sandia National Laboratories
University of Southern California
California Institute of Technology
NASA Ames Research Center

Introduction

A Working Group Meeting on Heavy Vehicle Aerodynamic Drag was held at Lawrence Livermore National Laboratory on March 28 and 29, 2001. The purpose of the meeting was to present and discuss technical details on the experimental and computational work in progress and future project plans. Due to the large participation from industry and other research organizations, a large portion of the meeting (all of the first day and part of the second day) was devoted to the presentation and discussion of industry's perspective and work being done by other organizations on the demonstration of commercial software and the demonstration of a drag reduction device. This report contains the technical presentations (viewgraphs) delivered at the Meeting, briefly summarizes the comments and conclusions, and outlines the future action items.

Industrial representatives from International Truck and Engine Corporation, PACCAR, and Freightliner participated in discussions and presented an industrial perspective. Representatives from Argonne National Laboratory presented an overview of computational results for heavy vehicles given to them by Adapco Corporation and a representative from Dynacs Corporation presented his plans for demonstration of a variety of commercial and NASA software packages. A representative of Georgia Technology Research Institute (GTRI) presented their experimental results and future plans for a drag reduction device developed by GTRI. The meeting introductory remarks included an overview of the Laboratory provided by a representative of LLNL's Energy Directorate.

Representatives from the Department of Energy (DOE) Office of Transportation Technology Office of Heavy Vehicle Technology (OHVT), Lawrence Livermore National

Laboratory (LLNL), Sandia National Laboratories (SNL), NASA Ames, University of Southern California's (USC), and California Institute of Technology (Caltech) gave presentations on the DOE Truck Aerodynamics Project and participated in discussions. The second day of the meeting included a review of experimental results and plans by the USC and NASA Ames, the computational results from LLNL and SNL for the integrated tractor-trailer benchmark geometry called the Ground Transportation System (GTS) Model, and turbulence model development and benchmark simulation for rounded cube shapes representative of a tractor and trailer being investigated by the Caltech. NASA Ames also presented information on the new geometry called the Generic Conventional Model (GCM) currently being evaluated in the 7x10 wind tunnel at NASA. Much of the second day discussion involved wind tunnel testing plans, analysis of existing experimental data, simulation results, and needed modeling improvements. One focus topic was the issue of careful verification and validation processes for software evaluation.

Summary of Major Issues

There were 3 major issues raised at the meeting.

1. A major topic of discussion was the process proposed for evaluation of NASA and commercial software. The Dynacs representative has proposed the evaluation of three separate NASA codes and three separate commercial codes for application to the Generic Conventional Model (GCM) by comparison of one or limited grid cases to experimental data. The question was raised whether the software could be evaluated without standard practices of verification and validation (e.g., demonstration of grid and time convergence)?

2. Another active topic of discussion was the DOE full-scale demonstration experiments proposed for the GTRI blowing device. A planning meeting at GTRI was suggested where industry participation will be encouraged.

3. The DOE Team has NEAR-term deliverables for FY01 that will be of value to industry in providing guidance in the use of RANS models. The fact that plans are to complete this effort by October 1st of this year was not made clear, and the Team was criticized for being 'too academic' and having deliverables that were 'too long term'. The Team did emphasize that they wish to present this information to industry and obtain feedback through an exchange of information during site visits and formal documentation. The majority was supportive of this communication approach.

Introduction, Overview of the Project, and Future Activities

After Ray Smith of LLNL gave an introduction to the Laboratory, Rose McCallen of LLNL presented the project overview. Some comments from the industry participants included

- Suggestion that an 'intermediary' for collaboration would be helpful,
- Separate meeting to update the multi-year program plan was recommended,
- Request that industry input be considered for wind tunnel model geometries, and
- Comment that industry wants near-term results.
-

Sid Diamond of DOE OHVT provided an update of the OHVT projects and budgets and some inspiring thoughts. He encouraged a consortium with industry with a 'modest' cost share from industry. His vision includes the involvement of not only the tractor manufacturers but also the added participation from trailer manufacturers, because of the well-recognized importance of integrating the tractor and trailer for reduction of aerodynamic drag.

The viewgraphs for the project introduction and LLNL overview are attached at the end of this report.

Industrial Perspective

Sunil Jain of International Truck and Engine Corporation emphasized that reducing drag is their objective and that the 21st Century Truck Initiative goal to reduce the drag by 25% over 20 years should be feasible with a strong team involving a tractor and trailer group. The wake and gap flow are the critical areas that need improvements for drag reduction. Sunil also provided an overview of the past and current aerodynamic effort at his company. International uses various commercial codes dependent on whether they are modeling internal, external components, or whole body flow. The predicted and measured drag are not always in agreement, but the commercial codes do provide a good match with wind tunnel pressures and good qualitative results. It is important, and often sufficient, to predict the correct *changes* in drag or *correct trends*. Typical problems involve 1-2 million zones, but can be up to 6-7 million zones. For underhood flows, changes in temperature need to be predicted to within 5%. Simple source and sink models for the fan are not adequate and more detailed models are required. The importance of understanding the flow phenomena, determining optimum vehicle shape to minimize drag, and to be able to correlate the computed and experimental drag coefficient was discussed. It was suggested that the DOE Truck Aero Team provide industry with the CFD tools they are using so that they can investigate their use. It was also suggested that the Team establish collaborative relationships with the commercial software industry providing advanced modeling guidance that will enhance those tools now being used by the tractor

manufacturers. Participation at the November 2001 SAE Truck and Bus Meeting in Chicago was encouraged. Further details are provided on Sunil's viewgraphs.

Dan Schlesinger of Freightliner provided an overview of market situations, overall development activities to reduce fuel consumptions, important issues in the design process to consider, aerodynamic testing, and CFD analysis. It was recognized that improvements in aerodynamic drag have the biggest payoff but the customer is not ready for an integrated tractor-trailer, the cubic capacity of the trailer can't be sacrificed so that a generous leading-edge radii is not acceptable, and bottails have overall length restrictions. It would be advantageous to have aerodynamics influence the design process upfront, but this is difficult if modifications or additions add cost, assembly time, complexity, or negatively impacts styling. It is also difficult to impact the design if the aerodynamic analysis takes too long. Wind tunnel testing can provide adequate changes in drag, but often not the absolute drag. CFD analysis is accomplished using commercial tools for internal flows, small-scale component analysis, and full body flow.

Everett Chu from PACCAR Technical Center provided an overview of his company's vehicle-aerodynamics development program including a description of their Heavy-Vehicle Manufacturing Divisions, methods used for product performance assurance, the use of CFD tools, wind tunnel experiments, and vehicle/track confirmation tools. PACCAR's Technical Center can provide support to it's other subsidiaries including Kenworth (US), Peterbilt (US), DAF (Netherlands), Foden (UK), and Leyland Trucks (UK). The Technical Center located in Mount Vernon, Washington has a 1.6-mile test track. Their product performance assurance follows a 4-stage development process including benchmarking and target setting, advanced concept, prototype validation, and product confirmation. CFD tools, wind tunnel experiments, and vehicle/track testing are part of this process. Different commercial CFD codes are used for application to underhood or external flows. Wind tunnel scaling issues (e.g., variation in results for different scale models) and several concerns involving the GCM design were mentioned (e.g., wheels too hidden, areas closed and open, cantilever of front end). Everett also provided input on the DOE program including 'helpful tools and techniques' and 'helpful analyses for specific vehicle areas and components' which are attached in the viewgraph section of this report.

Demonstration of Commercial Tools

Ross Sheckler of Dynacs Corporation presented his plans for the evaluation of 3 commercial and 3 NASA software packages. The focus of the discussion was on the proposed method of evaluation, as mentioned above, which is a 'best effort' approach. It was suggested that Ross document the criteria and evaluation process for review by the DOE Aero (SWAT) Team, and that both work towards some agreement in the approach. The results would then be submitted to DOE and industry for their review. Another topic was the use of vortex generators on the GCM during the wind tunnel experiments.

PACCAR representative, Everett Chu, mentioned that the vortex generators have been tested and that it is likely we will not see the results we are looking for. There was also discussion that our testing of the devices may be advertised as an endorsement for their use. Further details are provided in the attached viewgraphs.

Tanju Sofu of ANL presented some calculations performed by the software company Adapco using their code STARCD. Typical calculations involve roughly 10 million zones for simulation of automobile aerodynamics and 20-30 million zones for tractor-trailer simulations. Tabulated results are provided in the attached viewgraphs.

Aerodynamic Devices

Bob Englar of GTRI presented the results of wind tunnel experiments using a modified GTS with wheels, a gap between the tractor and trailer, with and without squared or rounded trailer leading and trailing edges, and tractor-trailer height mismatch. It was found that including the wheels on the GTS increased the drag. Rounding the leading edge of the trailer reduced the tractor-trailer height-mismatch imposed drag. Rounding the trailer rear corners is also helpful. Bob also presented the results of using a blowing device. Details can be found in the attached draft SAE paper to be presented at the 2001 SAE Government/Industry Meeting. Discussions on these results focused on plans for an upcoming demonstration full-scale field test. Questions raised were about the power source, what kind of instrumentation would be included on the field tests, what would be the cost of the tests, what are the ramifications of blowing: for example, would blowing have substantial drive-by noise, would icing be a problem, and what were the system maintenance issues. A meeting is scheduled in May in Atlanta to finalize the plans for the field tests and to further address some of these questions.

DOE Truck Aerodynamic ('SWAT') Team's Presentations

NASA's Current Tests on GCM in 7-ft x 10-ft Wind Tunnel Experiments and Plans for 12-ft Wind Tunnel Experiments

Jim Ross of NASA Ames presented the final report on the GTS 7-ft x10-ft experiments, some preliminary results on the 7-ft x10-ft experiments on the GCM which were started on March 19th, and the planning and preparation underway for the 12-ft pressure wind tunnel experiments with the GCM. Some of the parameters to be investigated with the GCM are Continuum Dynamics, Inc boattail plates, tractor trailing edge side extenders at two different lengths, vortex generators and under-slung cargo. Instrumentation will include 256 pressure taps, particle image velocimetry (PIV) in the tractor-trailer gap and at the trailer base, oil film interferometry (OIF) for measuring skin friction, unsteady pressure transducers at rear of side extenders, inside the gap surface and the back of the trailer, and independent measurement of tractor and trailer drag. The preliminary results with the GCM indicate a 'break' in the drag curve at 10°-yaw, which was not seen with

the GTS model. One hypothesis is that this characteristic is present because of the tractor-trailer gap flow. Jim also gave a reminder that the fairings on the bottom posts are not connected to the balance, so that one should not integrate over the fairing in calculating drag coefficients. Details of the NASA test plans are provided in the attached viewgraphs.

USC's Wind Tunnel Tests and a Look at an Aero Device

Fred Browand, Mustapha Hammache, and Albion Knight of USC gave an overview of their preparation work on the United Engineering Foundation Conference, a detailed presentation of their gap flow analysis, and a report on their progress in the development of a base drag reduction device. Fred has put together an advisory committee of outstanding internationally known researchers and industrial representatives from around the world for the United Engineering Foundation Conference on Aerodynamics of Trucks, Busses and Railcars planned for Fall of 2002. Mustapha presented his detailed analysis of the force coefficients as a function of gap and yaw angle. His preliminary conclusions are that at large yaw angles, there is a 'critical' gap where the tractor drag coefficient more than doubles with minimal effect on the trailer drag coefficient, unless the leading edge vertical sides of 'the trailer are rounded, and then trailer drag is also influenced by a 'critical' gap. Mustapha has also developed a novel approach for characterizing the gap flow by dividing the gap into two equal regions and comparing their 'gap outflow' velocities on a 'state space' plot using the PIV data. This method allows for evaluation of the gap flow in the various 'states' by use of conditional sampling based upon the location in the state space. With this type of guidance, industry can make intelligent technical (and economic) decisions on the use of aerodynamic devices for tractor-trailer modifications in the gap region. It was also mentioned that this information would be valuable to the manufacturers and installers of trailer refrigeration systems, who are concerned about air circulation in the gap where the refrigeration system is mounted on the trailer. Details of this described analysis can be found in the attached viewgraph presentation. Albion Knight gave a progress report on his plans for the development and testing of an oscillation device to control the trailer wake flow. The device is intended to alter the turbulent structure of the wake, resulting in a drag reduction. Details of the data acquisition and controls setup for testing the device and a preliminary experimental plan are provided in the attached viewgraphs.

RANS and DES Computations at SNL

Kambiz Salari of SNL gave an overview of the DOE Accelerated Strategic Computing Initiative (ASCI) and how it provides computer resources that can be utilized for this truck aerodynamics project. Kambiz also presented related issues of code verification and validation (V&V). Progress and status was reported on the Reynolds-averaged Navier Stokes (RANS) computational effort with the GTS geometry with some general findings of the predictive capability of RANS for simulation of a tractor-trailer configuration.

Information on the development and implementation of a detached-eddy simulation (DES) for application to the GTS model was also presented. (DES is a new turbulence modeling approach where RANS is used in wall regions and LES is used away from walls for reduced grid resolution requirements near walls.) Short-term deliverables for this fiscal year FY01 include careful evaluation of the application of RANS for modeling tractor-trailer drag and the transfer of this information to industry as guidance in their simulation process. SNL is investigating 4 different RANS models. The RANS calculations compare well with experiment except for the calculated pressure at the edges of the trailer base. It was recognized that accurate computation of the pressure gradient at the trailing edges of the trailer are essential for correctly determining the vehicle drag. The possible need for edge effect corrections by averaging the pressures for the perpendicular element segments at the edge was mentioned. Unfortunately, SNL has uncovered a 'bug' in their 'block patching' of computational grids. Even though it is believed that the above conclusions will not change, SNL has eliminated this problem and is currently rerunning the simulations to be sure there are no changes in their results. All scheduled tasks should still be completed on time, at the end of FY01. Details of the computations and analysis are provided in the attached viewgraphs.

Simulations using Vortex Methods: A Gridless Technique

Tony Leonard and Mike Rubel of Caltech gave an update on their progress in the effort to simulate a tractor-trailer configuration using a 'grid-free' (except for 2D grid on body surface) Vortex Method with improved, fast, parallelized, adaptive techniques. Current activities at Caltech include: incorporating bodies with arbitrary complexity, obtaining higher Reynolds numbers computations, and developing and analyzing subgrid models for large-eddy simulation. Using some demonstration calculations, Tony showed the need for 'vortex resolution' to capture the flow in the near wall region at turning edges around the tractor. Mike Rubel of Caltech provided an overview of his development work on a numeric time integration by 'dead reckoning'. This tool is needed to accelerate the vortex method for application to heavy vehicles. Details and results of computations with the vortex method code and on the turbulence modeling approach are in the attached viewgraphs.

LES/DES Incompressible Flow Computations/Analysis at LLNL

Rose McCallen, Tim Dunn, Roxana Greenman, and Jerry Owens of LLNL reported on the progress and status of their simulation effort. Rose described the near-term deliverables planned for this fiscal year, which include some general conclusions about the effectiveness of LES. Specifically, plans are to generate LES results of the GTS at zero yaw for direct comparison to the experimental data and the RANS simulations performed by SNL. This complimentary work should be of interest to industry, because it will supply them with some near term guidance on the adequacy of various turbulence models for application to predicting the base drag on a tractor-trailer. The approach and

development challenges were presented by Tim, recent validation results were presented by Roxana, and Jerry demonstrated a new graphics capability that provides movie generation with transparent contours. The code solution speed has in some cases increased by an order of magnitude with more effective use of a Finite Element Interface (FEI) and the introduction of stabilization and solver acceleration schemes. The V&V results for a flat plate, channel flow, and a sphere show good comparison with experiment. A simulation of the 7x10 NASA wind tunnel indicates promising projections of scaling and timing for LES simulations with the vehicle and tunnel. It was also demonstrated how with LES, stretched grids and adjustable parameters can be manipulated to produce widely different results. Thus, it is possible to 'tweek' parameters to match data, which is not a recommended approach. The LLNL team is struggling with a recent manpower shortage, but every attempt is being made so that scheduled tasks will be completed on time. See attached viewgraphs for details on the models.

Action Items

The follow-on action items with the individuals responsible for the tasks are as follows:

Unified Engineering Foundation Conference
- Set date and location (R. McCallen)
- Include more international representatives on advisory committee and finalize (F. Browand)
- Send letters requesting support (R. McCallen)

Generate draft document of code evaluation criteria and distribute to SWAT Team for review and then present to DOE and industry for comment (R. Sheckler)

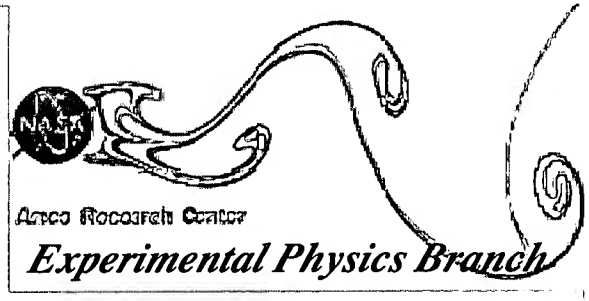
Review and comment on R. Sheckler's evaluation criteria (all)

Attend GTRI meeting in May (Rose, Mustapha)

Generate new SWAT Team budget estimate for FY02 before next meeting (R. McCallen)

Generate and distribute meeting report with viewgraphs (R. McCallen)

Establish location and schedule next working group meeting (R. McCallen)



Experimental Activities at Ames

Jim Ross
Dale Satran
Bruce Storms
JT Heineck
Steve Walker
Dave Driver

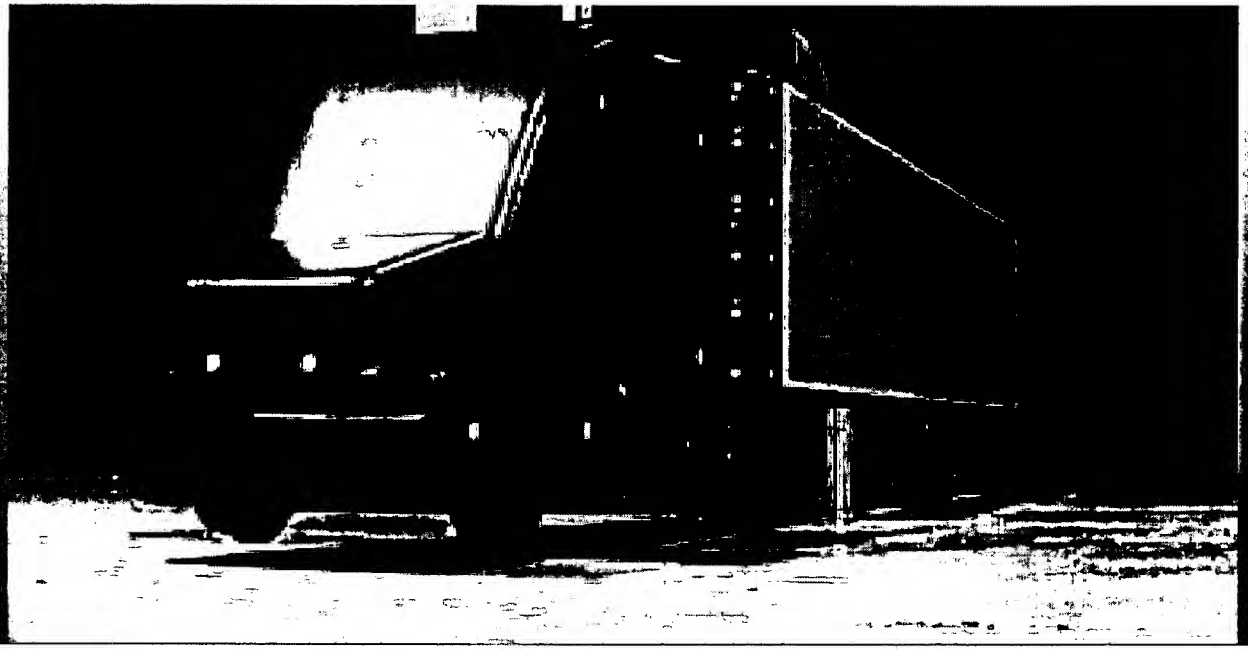
Heavy Vehicle Aerodynamic Drag
Working Group Meeting
3/29/01

CFD Validation Testing

- Report on 7x10 test of GTS model available
  - CD-ROM of complete data set included
- Second 7x10 test started 3/19
- Planning and prep work underway for test in 12' Pressure Wind Tunnel

Current Test - Generic Truck in 7x10

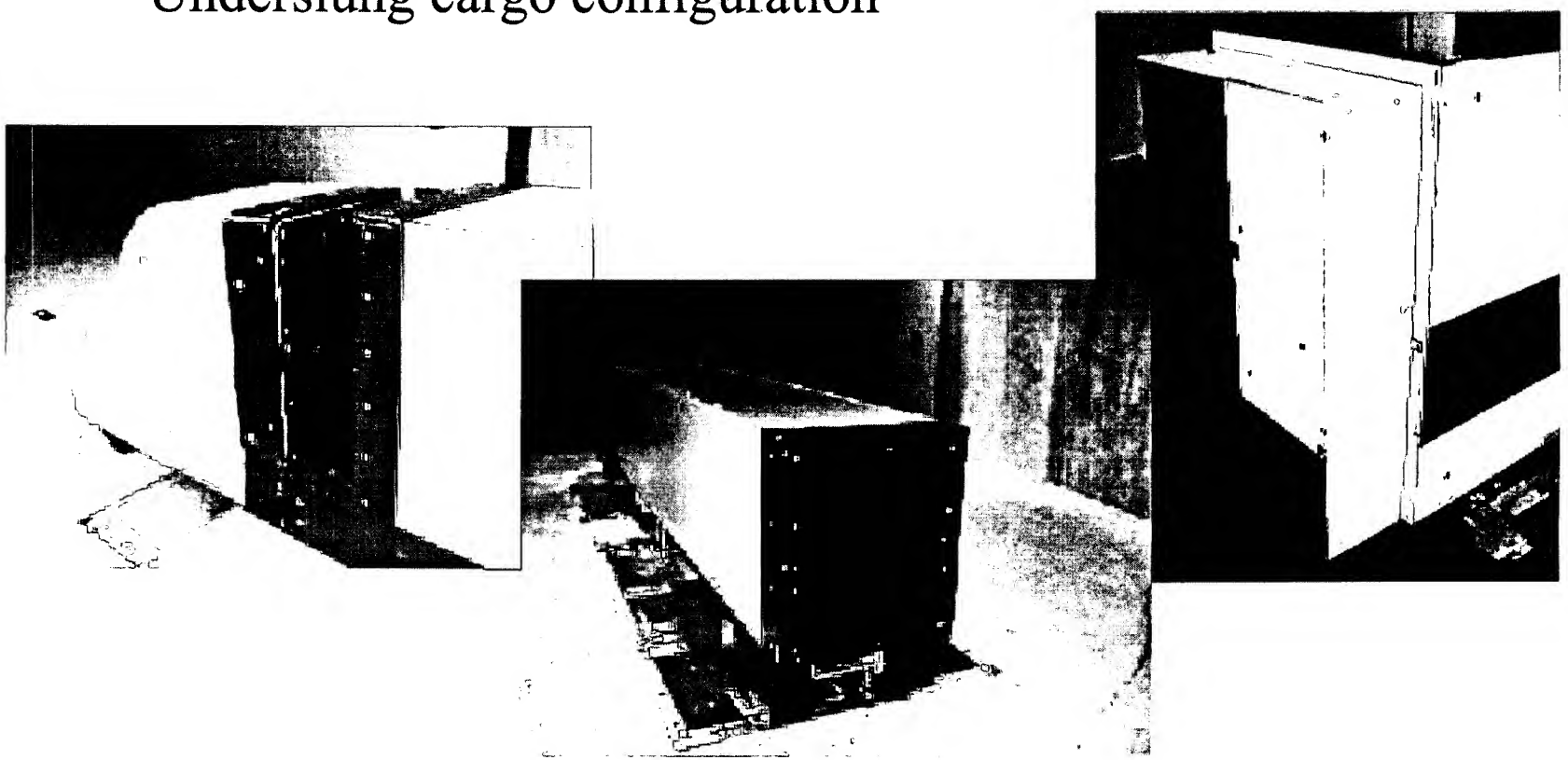
- 1/8th scale generic truck model in 7x10
- CFD validation test
  - Pressure distributions
  - Unsteady pressures in gap area, cab extenders, and rear door
  - 3-D PIV in gap
  - Oil film skin friction (limited configurations)
  - Independent measurement of tractor and trailer drag



Also looking at flow changes at yaw angles where abrupt drag changes occur - possible cases to observe with PIV

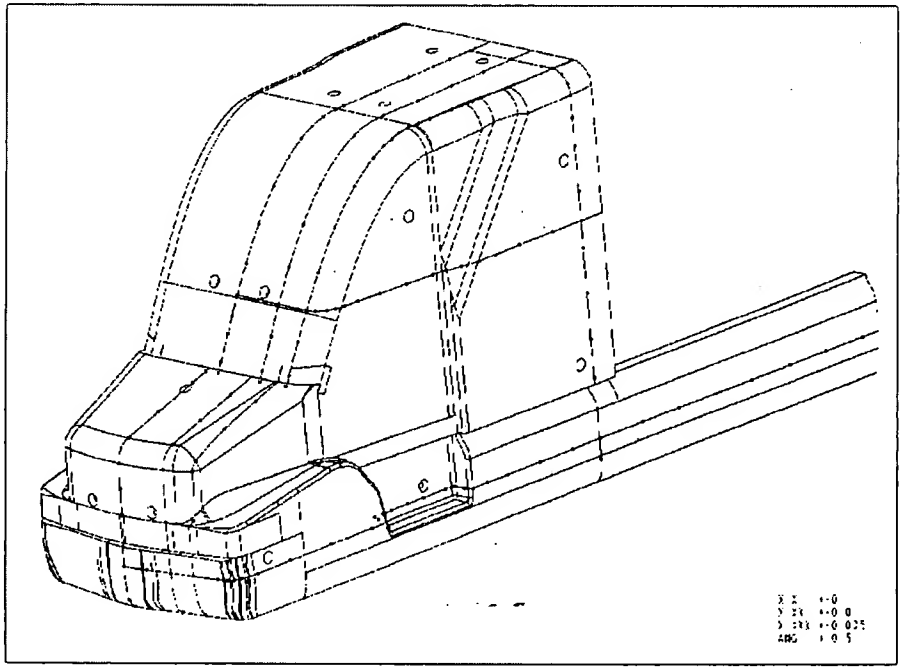
Test Configurations

- Side extender and gap variations for drag
- CDI boat-tail plates (drag delta with simple geometry change)
- Trailer vortex generators
- Underslung cargo configuration

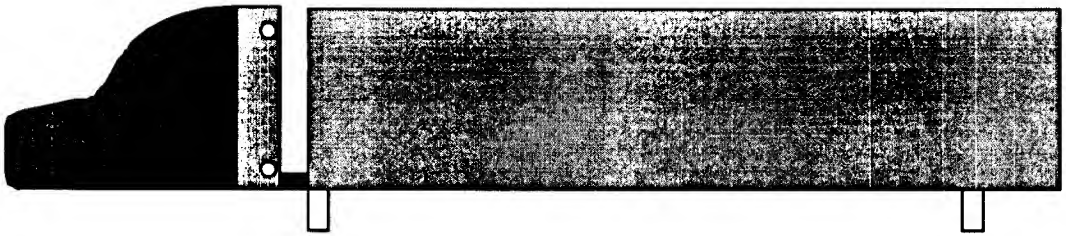


Surface Pressures

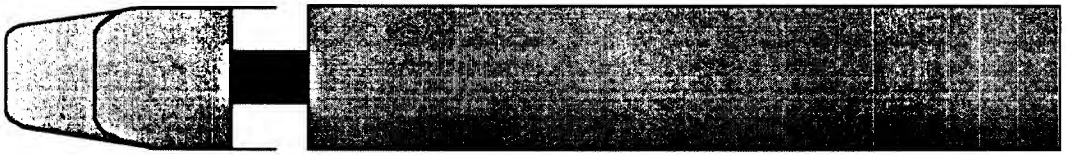
- 256 pressure taps
- No PSP - low absolute accuracy at test conditions
- Skin friction on tractor and trailer

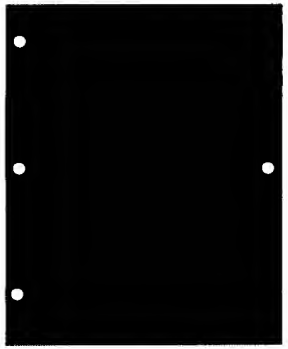


Unsteady Pressure Locations



Unsteady transducers at rear of side extenders on inside surface



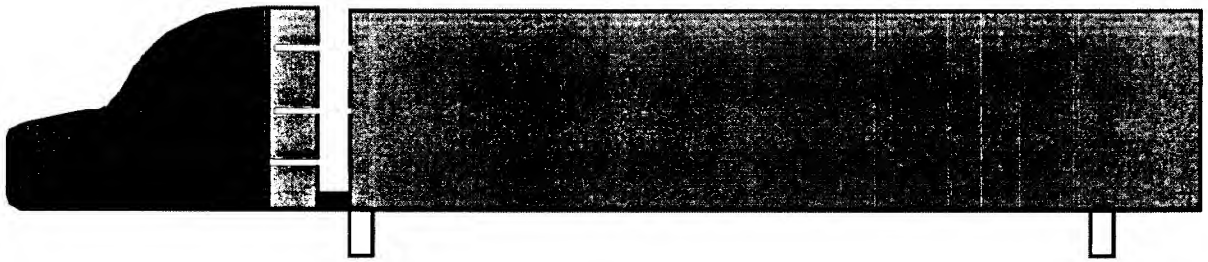


Pattern for unsteady transducers on back of tractor, front of trailer, and back of trailer

Will use Endevco 15psia transducers calibrated using piston phone

PIV Surveys

- Wake
  - 4 horizontal planes
  - 1 or 2 vertical cross planes
- Gap
  - With and without glass side extenders
  - 3 or 4 horizontal planes

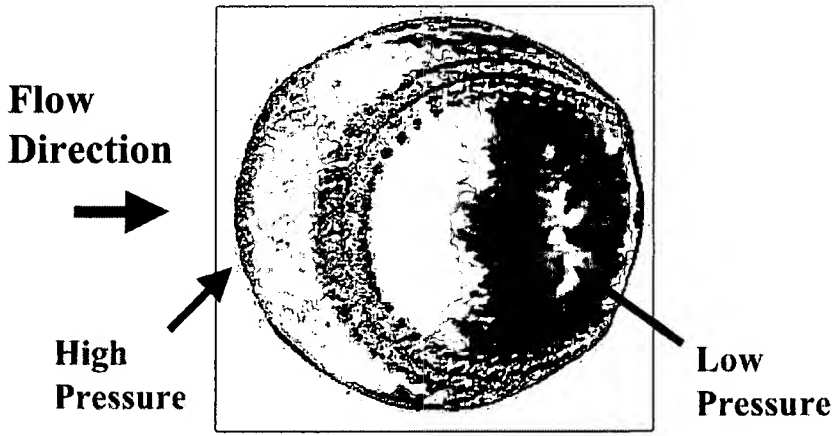


Test Status

- Aero data underway
- Tractor/trailer balance exceeding limits at high-q and yaw
  - Limited to 6 deg. at M = 0.27
  - 14 deg at M = 0.18
- PIV hardware fab done, installation next week
  - Modular mounting system will be used in 12' PWT test
- Need accurate installation measurements
  - Pricing in-situ laser scan

12' Experiment Objectives

- Generic tractor model
- Re effect on wind-averaged drag
  - Range from 0.5 to 5 million (based on width) at highway speed
- Re effect on drag components - *gap/side extenders*, mirrors, base-drag-reduction devices, etc. and associated flow physics
- CFD validation data
  - Skin friction
  - Pressure distributions
    - » PSP & electronic
  - Unsteady pressures
  - PIV



Pressure Sensitive Paint results on baseball at 120 mph at 1 atm. Much better at higher total pressure